Audel™

Pumps and Hydraulics

All New 6th Edition

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About the Authors

Rex Miller was a Professor of Industrial Technology at The State University of New York, College at Buffalo for more than 35 years. He has taught at the technical school, high school, and college level for more than 40 years. He is the author or co-author of more than 100 textbooks ranging from electronics through carpentry and sheet metal work. He has contributed more than 50 magazine articles over the years to technical publications. He is also the author of seven civil war regimental histories.

Mark Richard Miller finished his BS in New York and moved on to Ball State University, where he earned a master's degree, then went to work in San Antonio. He taught high school and finished his doctorate in College Station, Texas. He took a position at Texas A&M University in Kingsville, Texas, where he now teaches in the Industrial Technology Department as a Professor and Department Chairman. He has co-authored 11 books and contributed many articles to technical magazines. His hobbies include refinishing a 1970 Plymouth Super Bird and a 1971 Road-runner.

Harry L. Stewart was a professional engineer and is the author of numerous books for the trades covering pumps, hydraulics, pneumatics, and fluid power.

Introduction

The purpose of this book is to provide a better understanding of the fundamentals and operating principles of pumps, pump controls, and hydraulics. A thorough knowledge of pumps has become more important, due to the large number of applications of pump equipment in industry.

The applied principles and practical features of pumps and hydraulics are discussed in detail. Various installations, operations, and maintenance procedures are also covered. The information contained will be of help to engineering students, junior engineers and designers, installation and maintenance technicians, shop mechanics, and others who are interested in technical education and self-advancement.

The correct servicing methods are of the utmost importance to the service technician, since time and money can be lost when repeated repairs are required. With the aid of this book, you should be able to install and service pumps for nearly any application.

The authors would like to thank those manufacturers that provided illustrations, technical information, and constructive criticism. Special thanks to TAT Engineering and Sherwood Pumps.

Part I

Introduction to Basic Principles of Pumps and Hydraulics

Chapter 1

Basic Fluid Principles

Pumps are devices that expend energy to raise, transport, or compress fluids. The earliest pumps were made for raising water. These are known today as *Persian* and *Roman waterwheels* and the more sophisticated *Archimedes screw*.

Mining operations of the Middle Ages led to development of the *suction* or *piston pump*. There are many types of suction pumps. They were described by Georgius Agricola in his *De re Metallica* written in 1556 A.D. A suction pump works by atmospheric pressure. That means when the piston is raised, it creates a partial vacuum. The outside atmospheric pressure then forces water into the cylinder. From there, it is permitted to escape by way of an outlet valve. Atmospheric pressure alone can force water to a maximum height of about 34 feet (10 meters). So, the force pump was developed to drain deeper mines. The downward stroke of the force pump forces water out through a side valve. The height raised depends on the force applied to the piston.

Fluid is employed in a closed system as a medium to cause motion, either linear or rotary. Because of improvements in seals, materials, and machining techniques, the use of fluids to control motions has greatly increased in the recent past.

Fluid can be either in a liquid or gaseous state. Air, oil, water, oxygen, and nitrogen are examples of fluids. They can all be pumped by today's highly improved devices.

Physics

A branch of science that deals with matter and energy and their interactions in the field of mechanics, electricity, nuclear phenomena, and others is called *physics*. Some of the basic principles of fluids must be studied before subsequent chapters in this book can be understood properly.

Matter

Matter can be defined as anything that occupies space, and all matter has inertia. Inertia is that property of matter by which it will remain at rest or in uniform motion in the same straight line or direction unless acted upon by some external force. *Matter* is any substance that can be weighed or measured. Matter may exist in one of three states:

- Solid (coal, iron, ice)
- Liquid (oil, alcohol, water)
- Gas (air, hydrogen, helium)

Water is the familiar example of a substance that exists in each of the three states of matter (see Figure 1-1) as ice (solid), water (liquid), and steam (gas).

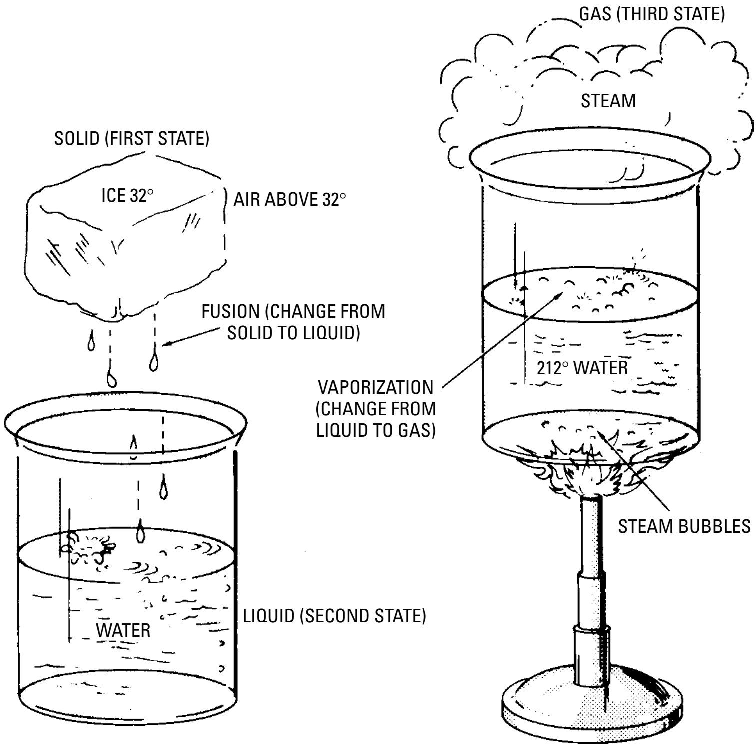

Figure 1-1 The three states of matter: solid, liquid, and gas. Note that the change of state from a solid to a liquid is called fusion, and the change of state from liquid to a gas is called vaporization.

Body

A body is a mass of matter that has a definite quantity. For example, a mass of iron 3 inches × 3 inches × 3 inches has a definite quantity of 27 cubic inches. It also has a definite weight. This weight can be determined by placing the body on a scale (either a lever or platform scale or a spring scale). If an accurate weight is required, a lever or platform scale should be employed. Since weight depends on gravity, and since gravity decreases with elevation, the reading on a spring scale varies, as shown in Figure 1-2.

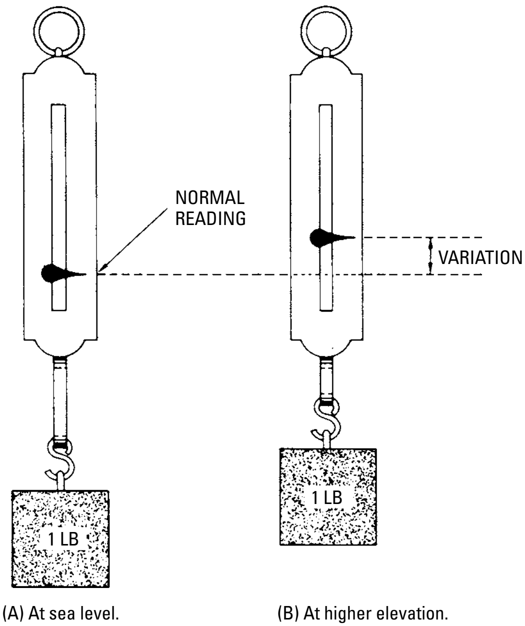

Figure 1-2 Variation in readings of a spring scale for different elevations.

Energy

Energy is the capacity for doing work and overcoming resistance. Two types of energy are *potential* and *kinetic* (see Figure 1-3).

Potential energy is the energy that a body has because of its relative position. For example, if a ball of steel is suspended by a chain, the position of the ball is such that if the chain is cut, work can be done by the ball.

Kinetic energy is energy that a body has when it is moving with some velocity. An example would be a steel ball rolling down an incline. Energy is expressed in the same units as work (foot-pounds).

As shown in Figure 1-3, water stored in an elevated reservoir or tank represents potential energy, because it may be used to do work as it is liberated to a lower elevation.

Conservation of Energy

It is a principle of physics that energy can be transmitted from one body to another (or transformed) in its manifestations, but energy may be neither created nor destroyed. Energy may be dissipated.

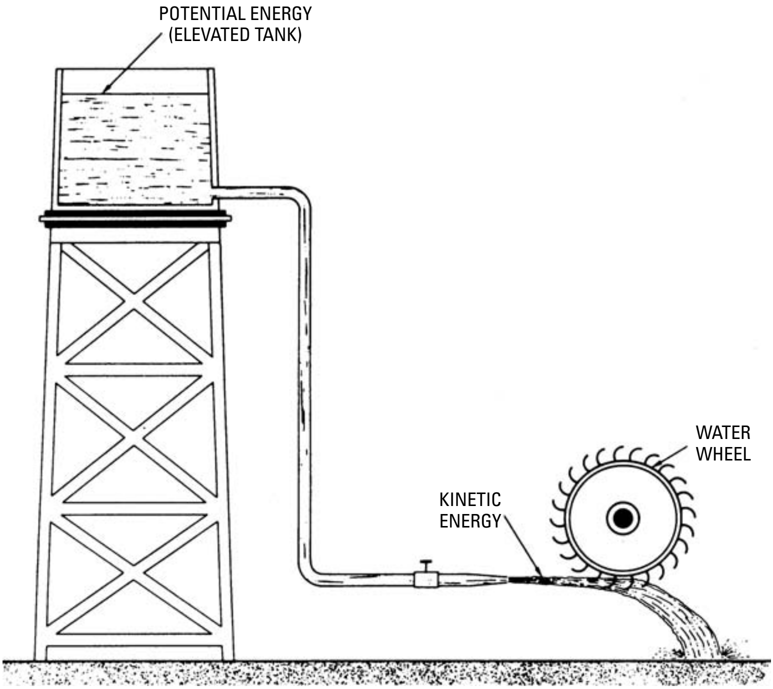

Figure 1-3 Potential energy and kinetic energy.

That is, it may be converted into a form from which it cannot be recovered (the heat that escapes with the exhaust from a locomotive, for example, or the condensed water from a steamship). However, the total amount of energy in the universe remains constant, but variable in form.

Joule's Experiment

This experiment is a classic illustration (see Figure 1-4) of the conservation of energy principle. In 1843, Dr. Joule of Manchester, England, performed his classic experiment that demonstrated to the world the mechanical equivalent of heat. It was discovered that the work performed by the descending weight (*W* in Figure 1-4) was not lost, but appeared as heat in the water—the agitation of the paddles having increased the water temperature by an amount that can be measured by a thermometer. According to Joule's experiment, when 772 foot-pounds of work energy had been expended on the 1 pound of water, the temperature of the water had increased 1°F.

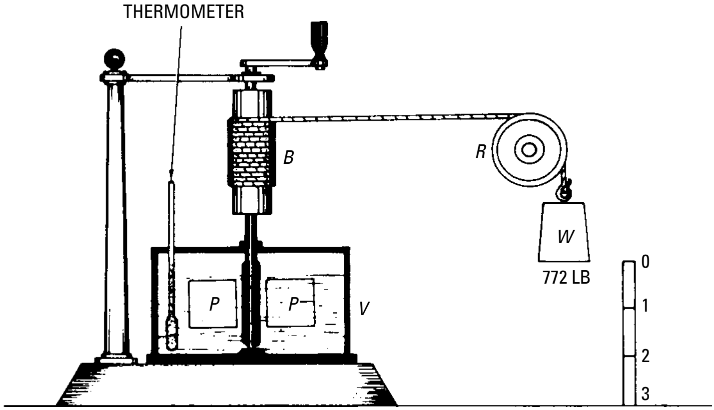

Figure 1-4 Joule's experiment revealed the mechanical equivalent of heat.

This is known as *Joule's equivalent*: That is, 1 unit of heat equals 772 foot-pounds (ft-lb) of work. (It is generally accepted today that ft-lb. be changed to lb.ft. in the meantime or transistion period you will find it as ft-lb. or lb.ft.)

Experiments by Prof. Rowland (1880) and others provide higher values. A value of 778 ft-lb is generally accepted, but 777.5 ft-lb is probably more nearly correct, the value 777.52 ft-lb being used by Marks and Davis in their steam tables. The value 778 ft-lb is sufficiently accurate for most calculations.

Heat

Heat is a form of energy that is known by its effects. The effect of heat is produced by the accelerated vibration of molecules. Theoretically, all molecular vibration stops at –273°C (known as absolute zero), and there is no heat formed. The two types of heat are *sensible* heat and *latent* heat.

Sensible Heat

The effect of this form of heat is indicated by the sense of touch or feeling (see Figure 1-5).

Sensible heat is measured by a thermometer. A thermometer is an instrument used to measure the temperature of gases, solids, and liquids. The three most common types of thermometers are *liquid-in-glass*, *electrical*, and *deformation*.

The liquid-in-glass generally employs mercury as the liquid unless the temperature should drop below the freezing point of mercury,

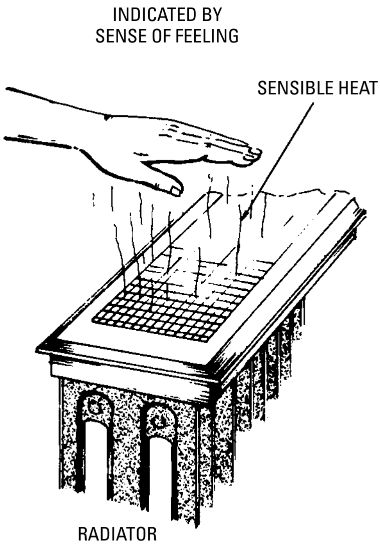

Figure 1-5 The radiator is an example of sensible heat.

in which case alcohol is used. The liquid-in-glass is relatively inexpensive, easy to read, reliable, and requires no maintenance. The thermometer consists of a glass tube with a small uniform bore that has a bulb at the bottom and a sealed end at the top. The bulb and part of the tube are filled with liquid. As the temperature rises, the liquid in the bulb and tube expand and the liquid rises in the tube. When the liquid in the thermometer reaches the same temperature as the temperature outside of the thermometer, the liquid ceases to rise.

In 1714, Gabriel Daniel Fahrenheit built a mercury thermometer of the type now commonly in use.

Electrical thermometers are of the more sophisticated type. A *thermocouple* is a good example. This thermometer measures temperatures by measuring the small voltage that exists at the junction of two dissimilar metals. Electrical thermometers are made that can measure temperatures up to 1500°C.

Deformation thermometers use the principle that liquids increase in volume and solids increase in length as temperatures rise. The *Bourdon tube thermometer* is a deformation thermometer.

Extremely high temperatures are measured by a *pyrometer*. One type of pyrometer matches the color (such as that of the inside of a furnace) against known temperatures of red-hot wires.

Figure 1-6 shows the Fahrenheit, Celsius, and Reaumur thermometer scales. Figure 1-7 illustrates the basic principle of a thermocouple pyrometer.

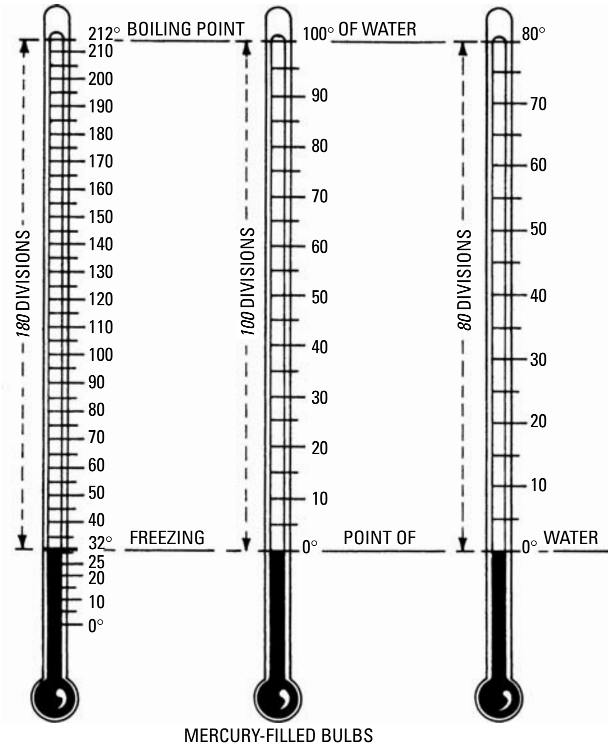

Figure 1-6 Three types of thermometer scales.

Latent Heat

This form of heat is the quantity of heat that becomes concealed or hidden inside a body while producing some change in the body other than an increase in temperature.

When water at atmospheric pressure is heated to 212°F, a further increase in temperature does not occur, even though the supply of heat is continued. Instead of an increase in temperature, vaporization occurs, and a considerable quantity of heat must be added to the liquid to transform it into steam. The total heat consists of *internal* and *external* latent heats. Thus, in water at 212°F and at

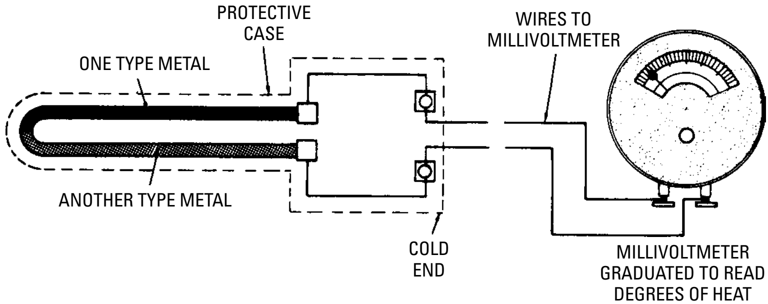

Figure 1-7 Basic principle of a thermocouple pyrometer. A thermocouple is used to measure high temperatures. In principle, when heat is applied to the junction of two dissimilar metals, a current of electricity begins to flow in proportion to the amount of heat applied. This current is brought to a meter and translated in terms of heat.

atmospheric pressure, considerable heat is required to cause the water to begin boiling (internal latent heat). The additional heat that is required to boil the water is called *external latent heat*. Figure 1-8 shows a familiar example of both internal and external latent heat.

(A) Internal latent heat—waiting for the pot to boil.

(B) External latent heat—when the pot boils.

Figure 1-8 Domestic setting for illustrating internal (left) and external (right) latent heat.

Unit of Heat

The *heat unit* is the amount of heat required to raise the temperature of 1 pound of water 1°F at the maximum density of the water. The *British thermal unit* (abbreviated Btu) is the standard for heat measure. A unit of heat (Btu) is equal to 252 calories, which is the